Quality of Roof Harvested Rainwater in Akwa Ibom State, Southern Nigeria.

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Abstract – This study assesses the concentration of micro pollutants (heavy metals – Cu, Fe, Ni, Pb) in rainwater from various roofing materials and ambient source in southern Nigeria. The physicochemical properties of rainwater samples are also analyzed using standard procedures. Rainwater harvested from various rooftops indicates a mean pH of 6.68 and a value of 6.02 for the ambient rainwater. Conductivity ranged from 4.96 – 67.4 µS/cm and may be due to the dissolution of deposited aerosols and leaching of roofing materials. Turbidity and Cu exceeded allowable limits for drinking water with inputs from the rooftops. Total dissolve solid (TDS) concentration were generally low compared with WHO's allowable limits for drinking water. Significant presence of heavy metals has also been noted in the rainwater. Water quality from asbestos was the worst among the various roof runoffs examined. Results indicate that rainwater in the region requires proper treatment before ingestion although it could be directly used for regular washing. The activities of the oil and gas exploration companies in the region could contribute to the contaminants noted in the results. While runoffs from the various roof materials could be directly used after light treatment, rainwater runoffs from asbestos roof should be thoroughly treated before usage. Results from this study would be useful for city planning and with proper treatment, may benefit the promotion of rainwater as alternative water supply towards avoiding flood and water scarcity.

Index Terms – Metals, Physicochemical, Pollutant, Roof, Rainwater, Uyo

1 Introduction

The ever increasing global industrial agricultural and domestic use of water has led to greater concern for a cleaner environment. They also gave rise to various policy enactments by governments to protect the environment. In spite of efforts, environmental pollution, especially water and land resources, remains a challenge [18]. Rainwater is a type of precipitation, a product of the condensation of atmospheric water vapour that is deposited on the earth's surface. Rainwater is usually considered pure, being produced by a form of distillation, however, it contains dissolved gases such as carbon-dioxide, sulphur dioxide, ammonia etc, from the atmosphere.

Rainfall constitutes one of the largest sources of water in Nigeria especially the rural areas. Many rural and urban households in Africa rely on rainwater harvested from roof catchments to provide water for usage [1].

Rainwater harvesting (RWH) is the collection of rainwater from a surface known as catchment (roofs and ground surfaces), and its storage in physical structures or within the soil profile ([20]; [28]; [1]). This is a strategy that brings many benefits and may serve to cope with current water shortages, urban stream degradation and flooding ([7]; [26]; [29]). Roofs are the first candidates for RWH systems because their runoff is often regarded to be unpolluted ([6]; [8]) or at least, it presents relatively good quality standard compared to the rainwater from surface catchment areas [9]. Nevertheless, there is still some disagreement about the quality of roof runoff water; the assessment of rooftop runoff quality ranges from good or acceptable (for example, [2]; [15]; [23]) to severely polluted (example, [4]; [10]; [21]). Urban residential roofs are made up of different materials containing compounds that can leach into rainwater with atmospherically deposited materials that easily dissolve into the runoff ([22]; [28]; [1]). Nitrate nitrogen (NO3-N) and ammonium nitrogen (NH4-N) are primary indicators of water quality [14]. Aside from the general release of harmful and toxic emissions into the atmosphere in Akwa Ibom State by industries, current increase in human capital and influx of vehicles has significantly affected the environment of the state. Consequently, we seek to investigate rainwater collected in the state in order to assess the level of infiltration of any emission capable of endangering the inhabitants of this region.

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2 Description of the Region

Because of the effects of the Maritime and continental tropical air masses, the climate of Akwa Ibom State is characterized by two seasons, the wet or rainy season and the dry season. In the south and central parts of the state, the wet or rainy season lasts for about eight months but towards the far north, it is slightly less. The rainy season begins about March – April and lasts until mid – November. Akwa Ibom State receives relatively higher rainfall totals than other parts of southern Nigeria. The total annual rainfall varies from 4000 mm along the coast to 2000 mm inland. Temperature values are relatively high in Akwa Ibom State throughout the year, with the mean annual temperatures varying between about 26 °C to

36 °C. Akwa Ibom State has relative humidity varying between 75 – 95%, with the highest and lowest values in July and January respectively [19].

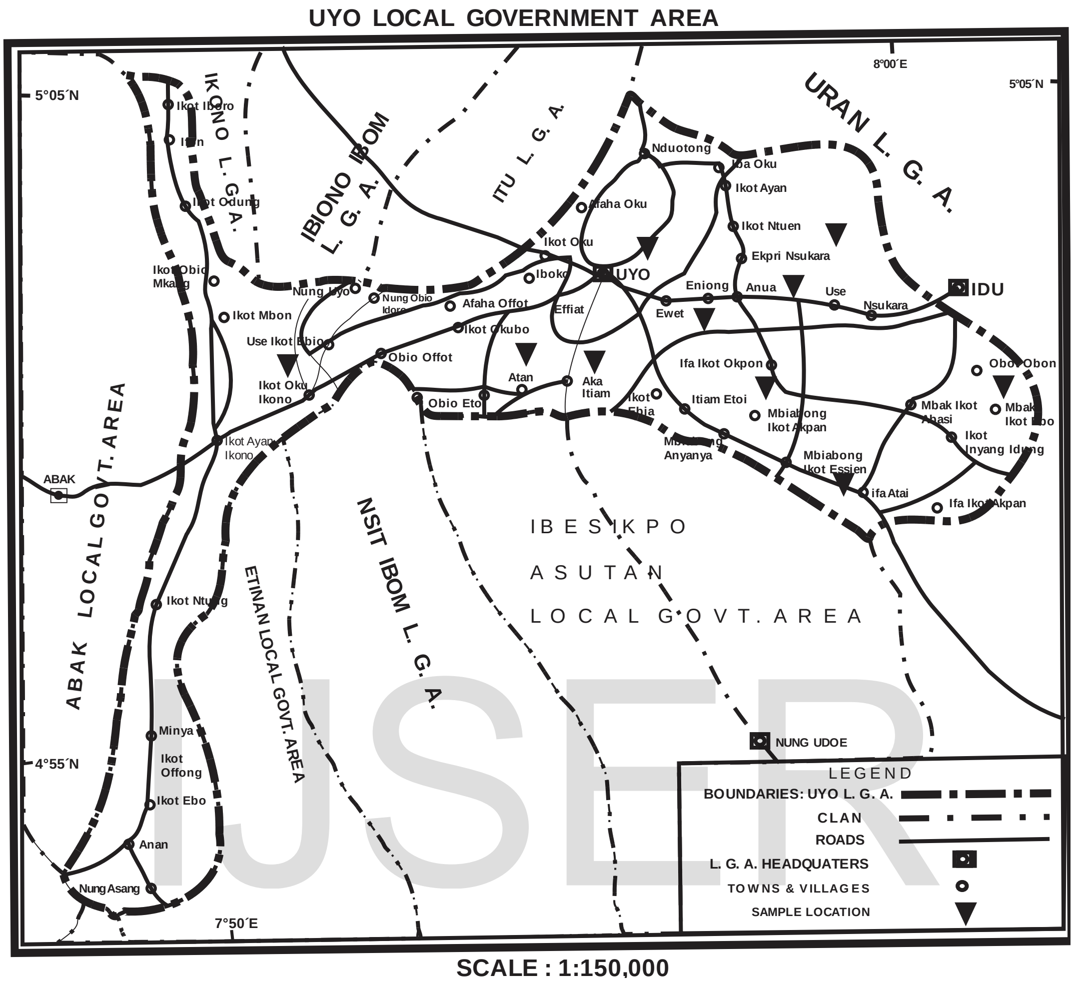

Figure 1: Map of Uyo Local Government Area and environs showing sample locations

We selected Uyo Local Government Area (Akwa Ibom State Capital)(Figure 1) which is located in the center of the state and has a vast number of villages, to represent our case study. Uyo is a fast growing metropolitan city with rapid industrial expansion.

3 Experimental

3.1 Categories of Roof

The methodology adopted for this work included laboratory analysis of residential roof runoff and bulk open precipitation (ambient rainwater). Temperatures of the samples were recorded. A total of ten (10) individual communities were chosen to conduct the sample acquisition. The selection of roofs, the main characteristics of which are shown in Table 1, included; recent galvanized iron sheet, rusted galvanized iron sheet, thatch roof, asbestos, aluminum longspan sheet of various colour coating. Theses roof types are common roofing used in the metropolis with aluminum longspan sheets, popular with larger buildings.

TABLE 1.
Sample location with roof type.

Sample	Location	Roof Type
A	Atan	Asbestos
B	Aka	Red coated aluminum
C	Anua	Recent galvanized iron
D	Ekpri Nsukara	Thatch
E	Ewet	Brown coated aluminum
F	Uyo	Aluminum longspan
G	Itiam Etoi	Blue coated aluminum
H	Mbiabong Ikot Essien	Rusted galvanized iron
I	Ikot Oku Ikono	Green coated aluminum
J	Ikot Ebo	Cameroon zinc

The selected sites represent adequate model spacing distribution for evaluating rainwater quality in the study region. Samples were collected from 10 roofing materials and ambient source (that is, directly from the atmosphere but within the vicinity of the roof sources for easy labeling). All containers for the samples were washed thoroughly and rinsed with distilled water before usage.

4 Results

Sample pH, temperature, conductivity, total suspended solids (TSS), total dissolved solids (TDS) and electrical conductivity were determined by standard procedures ([3]; [1]). Turbidity was determined using the Hach turbidity meter model 2100A [11]. Samples were also analyzed for the inorganic ions Cl, NO3-,NO2,SO42-,PO43-,NH3, and Ca. Concentration of heavy metals (Fe, Cu, Ni, Pb) in ambient rainwater and roof runoff were determined using a computerized Buck scientific model 210 VGP atomic absorption spectrometer (AAS). Standard solutions of the respective metals were used for instrument calibration and all chemicals were of analytical grade. Results of the physicochemical investigation of rain water samples collected from various roofs are shown in Tables 2 and 3. Tables 4 and 5 shows similar evaluations for direct source (ambient rainwater) collected in the vicinity closer to the roof type. Results for heavy metals in the rainwater from different roofing materials and direct source are shown in Tables 6 and 7 respectively.

TABLE 2
Physicochemical Parameters of Rainwater from Various Roofs.

SAMPLE	A	B	C	D	E	F	G	H	I	J
PARAMETERS	ABESTORS ROOF	RED ROOF	SWAN ROOF	THATCH ROOF	RUSTED ROOF	BROWN ROOF	BLUE ROOF	GREEN ROOF	CAMEROON ROOF	LONGSPAN AND ROOF
TEMPERATURE (℃)	26.00	28.00	25.00	28.00	27.00	26.00	27.00	27.00	26.00	27.00
pH	7.33	5.74	7.74	6.13	5.46	5.75	8.46	5.85	6.07	8.33
CONDUCTIVITY (µS/cm)	63.1	11.86	25	27.4	9.53	4.96	67.4	9.91	7.93	13.72
SALINITY (%)	0	0	0	0	0	0	0	0	0	0
TOTAL DISSOLVED SOLID (mg/L)	29.8	5.10	11.4	12.6	4.00	1.80	31.60	4.20	3.30	6.00
DISSOLVED OXYGEN (NTU)	0	0.10	0	0.20	0.10	0.20	0.20	0.20	0.10	0.20
TURBIDITY (NTU)	4.20	6.48	11.16	15.40	5.06	6.94	12.60	10.20	9.10	6.86
TOTAL HARDNESS (mg/L)	90.00	80.00	70.00	100.00	60.00	62.00	62.00	50.00	70.00	50.00
CALCIUM HARDNESS (mg/L)	90.00	40.00	60.00	100.00	40.00	26.00	58.00	66.00	60.00	40.00
MAGNESSIUM HARDNESS (mg/L)	0	40.00	10.00	0	20.00	36.00	4.00	16.00	10.00	10.00
ALKALINITY (mg/L)	7.20	9.60	1.20	9.60	13.20	27.60	8.40	8.40	1.2.00	7.20
CHLORIDE (mg/L)	4.96	2.84	1.42	3.55	3.55	2.13	3.55	0.71	0.70	2.13
NITRATE (NO3)	0.05	0.03	0.01	0.05	0.01	0.01	0.05	0.03	0.02	0.02
NITRATE (NO2)$\times 10^{-2}$	0.08	0.06	0.03	0.10	0.03	0.03	0.08	0.05	0.02	0.03
AMMONIA (NH3)	0	0	0	0	0	0	0	0	0	0
PHOSPHATE (PO_4^{3-})	0.05	0.02	0.02	0.01	0.03	BD	0.01	0.04	0.01	BD
TOTAL SUSPENDED SOLID	11.00	6.00	2.00	7.00	3.00	0	11.00	5.00	3.00	BD
SULPHATE (SO_4^{2-})	6.00	5.00	2.00	8.00	2.00	2.00	6.00	4.00	3.00	3.00

BD = Below Detectable

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TABLE 3
Range, mean and standard deviation of the rainwater samples from roof sources.

PARAMETERS	RANGE	MEAN	STANDARD DEVIATION
TEMPERATURE (℃)	25.00 - 28.00	26.50	0.95
pH	5.46 - 8.46	6.68	1.16
CONDUCTIVITY (µS/cm)	9.46 – 67.40	24.08	5.82
SALINITY (%)	0	0	0
TOTAL DISSOLVED SOLID (mg/L)	1.80 – 31.60	10.98	10.95
DISSOLVED OXYGEN (NTU)	0. - 0.20	0.12	0.21
TURBIDITY (NTU)	4.20 – 15.40	8.84	5.72
TOTAL HARDNESS (mg/L)	50.00 – 100.00	69.40	12.86
CALCIUM HARDNESS (mg/L)	26.00 – 100.00	58.00	23.23
MAGNESSIUM HARDNESS (mg/L)	0 – 40.00	11.40	10.68
ALKALINITY (mg/L)	1.20 – 27.60	9.96	6.88
CHLORIDE (mg/L)	0.71 – 4.96	2.55	1.39
NITRATE (NO3)	0.01 – 0.05	0.03	0.02
NITRATE (NO2) $\times 10^{-2}$	0.10 – 0.20	0.51	0.19
AMMONIA (NH3)	0	0	0
PHOSPHATE (PO_4^{3-})	0.01 – 0.47	0.66	0.02
TOTAL SUSPENDED SOLID	0 – 11.00	4.80	3.66
SULPHATE (SO_4^{2-})	2.00 – 8.00	4.10	2.08

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Table 4
Physicochemical parameters of ambient rainwater from direct source.

SAMPLE	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1
*PARAMETERS	ABESTORS ROOF	RED ROOF	SWAN ROOF	THATCH ROOF	RUSTED ROOF	BROWN ROOF	BLUE ROOF	GREEN ROOF	CAMEROON ROOF	LONGSPAN AND ROOF
TEMPERATURE (℃)	26.00	27.00	27.00	28.00	26.00	27.00	27.00	27.00	25.00	27.00
pH	7.26	5.58	7.06	5.13	5.73	5.38	6.32	5.22	6.88	5.61
CONDUCTIVITY (µS/cm)	57.40	16.46	6.80	23.90	6.37	14.08	13.96	10.21	4.03	26.90
SALINITY (%)	0	0	0	0	0	0	0	0	0	0
TOTAL DISSOLVED SOLID (mg/L)	26.90	7.30	2.70	10.90	2.50	6.20	6.20	4.40	1.40	12.30
DISSOLVED OXYGEN (NTU)	0	0.20	0.20	0.20	0.10	0.20	0.20	0.20	0	0.20
TURBIDITY (NTU)	3.20	10.60	6.25	10.70	5.59	7.40	6.82	11.70	2.30	9.17
TOTAL HARDNESS (mg/L)	100.00	64.00	60.00	80.00	72.00	44.00	60.00	60.00	90.00	80.00
CALCIUM HARDNESS (mg/L)	70.00	40.00	40.00	80.00	64.00	30.00	30.00	60.00	40.00	50.00
MAGNESSIUM HARDNESS (mg/L)	30.00	24.00	20.00	0	8.00	14.00	30.00	0	50.00	30.00
ALKALINITY (mg/L)	9.60	18.00	15.60	13.20	7.20	15.60	9.60	14.40	10.80	7.20
CHLORIDE (mg/L)	1.42	2.84	2.13	5.67	6.38	1.42	2.13	2.13	1.42	2.13
NITRATE (NO3)	0.02	0.04	0.02	0.05	0.02	0.02	0.04	0.04	0.01	0.02
NITRATE (NO2)$\times 10^{-2}$	0.05	0.07	0.04	0.01	0.03	0.04	0.07	0.06	0.02	0.03
AMMONIA (NH3)	0	0	0	0	0	0	0	0	0	0
PHOSPHATE (PO_4^{3-}))$\times 10^{-2}$	0.08	0.16	0.16	0.28	0.09	0.28	0.29	0.33	0.13	0.11
TOTAL SUSPENDED SOLID	1.00	8.00	3.00	7.00	1.00	2.00	6.00	6.00	BD	0
SULPHATE (SO_4^{2-})	3.00	5.00	3.00	8.00	2.00	3.00	5.00	3.00	1.00	3.00

BD = Below Detectable
* = This was taken directly within the premise of the roof type but not from the roof source

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Table 5
Range, mean and standard deviation of the rainwater samples from direct sources

*PARAMETERS	RANGE	MEAN	STANDARD DEVIATION
TEMPERATURE (℃)	25 - 28	26.70	0.82
pH	5.31 – 7.26	6.02	0.80
CONDUCTIVITY (μS/cm)	4.03 - 57.40	18.01	9.66
SALINITY (%)	0	0	0
TOTAL DISSOLVED SOLID (mg/L)	1.40 - 26.90	8.08	4.56
DISSOLVED OXYGEN (NTU)	0 - 0.20	0.15	0.15
TURBIDITY (NTU)	2.3 - 11.70	7.37	4.28
TOTAL HARDNESS (mg/L)	44.00 – 100.00	71.00	16.69
CALCIUM HARDNESS (mg/L)	30.00 – 80.00	50.40	17.30
MAGNESSIUM HARDNESS (mg/L)	0 – 50.00	20.60	15.60
ALKALINITY (mg/L)	7.20 – 18.00	12.12	3.77
CHLORIDE (mg/L)	1.42 – 6.38	2.77	1.78
NITRATE (NO3)	0.01 – 0.05	0.03	0.02
NITRATE (NO2) $\times 10^{-2}$	0.02 – 0.10	0.51	0.48
AMMONIA (NH3)	0	0	0
PHOSPHATE (PO_4^{3-})	0.08 – 0.33	0.19	0.94
TOTAL SUSPENDED SOLID	0 – 8.00	3.40	3.06
SULPHATE (SO_4^{2-})	1.00 – 8.00	3.60	1.96

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Table 6
Results for heavy metals from different roofing materials.

SAMPLE	A	B	C	D	E	F	G	H	I	J			
PARAMET ERS	ABESTO RS ROOF	RED ROO F	SWA N ROO F	THATC H ROOF	RUSTE D ROOF	BROW N ROOF	BLU E ROO F	GREE N ROOF	CAMERO ON ROOF	LONGSP AN AND ROOF	RAN GE	MEA N	STANDA RD DEVIATI ON
Fe (mg/L)	0.007	0.017	0.009	0.052	0.015	0.008	0.049	0.038	0.037	0.006	0.052 – 0.006	0.024	0.027
Cu (mg/L)	0.003	0.022	0.003	0.021	0.008	0.003	0.007	0.005	0.002	0.001	0.001 – 0.022	0.094	0.089
Ni (mg/L)	0.041	0.008	0.001	0.016	0.004	0.002	0.004	0.001	0.011	BDL	0.001 – 0.041	0.088	0.079
Pb (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.003	BDL	BDL – 0.003	0.003	BDL

BDL = Below Detectable Limit

Table 7
Heavy metals from ambient rainwater (Direct sources)

SAMPLE	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1			
*PARAMET ERS	ABESTO RS ROOF	RED ROO F	SWA N ROO F	THATC H ROOF	RUSTE D ROOF	BROW N ROOF	BLU E ROO F	GREE N ROOF	CAMERO ON ROOF	LONGSP AN AND ROOF	RAN GE	MEA N	STANDA RD DEVIATI ON
Fe (mg/L)	0.055	0.019	0.006	0.039	0.053	0.005	0.045	0.008	0.011	0.036	0.005 – 0.055	0.028	0.031
Cu (mg/L)	0.002	0.013	0.002	0.015	0.005	0.001	0.004	0.002	0.008	0.009	0.001 – 0.015	0.061	0.049
Ni (mg/L)	0.028	0.005	BDL	0.007	0.008	0.005	0.003	BDL	0.005	0.007	0.003 – 0.028	0.068	0.056
Pb (mg/L)	0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.002	BDL – 0.002	0.000 3	6.137

BDL = Below Detectable Limit

5 Discussion

Roofing materials are generally responsible for the presence of toxic pollutants such as Cu, Zn, cadmium and Pb that leach from the materials into the runoff ([25]; [16]). The leached materials contribute relatively high pollutant loads to the runoff and hence significantly contaminate harvested rainwater ([5]; [17]; [28]; [1]). The results from our analysis show that some samples have higher values of turbidity, higher than the specification of 5, by World Health Organization (WHO). Higher turbidity is seen in samples B, B1, C, C1, D, D1, H and H1. These samples do not meet specification requirements, necessitating proper treatment before usage. Calcium hardness evaluation shows that few samples have calcium hardness higher than required specification as the mean value of calcium hardness is 58. We observed a mean value of 50.4 for the ambient rainwater source, clearly indicating higher value for roofing materials than direct source.

Total hardness, a combination of calcium and magnesium hardness, is present in water in the form of $CaCO_3$. The absence of calcium renders water soft. We obtained a mean calcium hardness for the various roofs examined as 58 and a value of 50.4 for the ambient rainwater.

The pHs of the harvested rainwater from the various roofs were generally higher than that of ambient rainwater with a range of 5.46 – 8.46 for the roof runoffs and 5.13 – 7.26 for ambient rainwater. A pH value of between 5 and 6, indicates acidic rainwater. Samples collected from rooftop materials exhibited a conductivity ranging between 4.96 – 67.4 µS/cm and ambient rainwater ranged between 4.03 – 57.4 µS/cm. These compares with Mendez et al. (2010) range of 18 – 61 µS/cm. Rainwater from the different rooftops displayed higher conductivity than the ambient collection. This may be due to the initial dissolution of deposited aerosols and weathering products, followed by continuous leaching of roofing material [1]. Turbidity readings show highest turbidity of 12.6 NTU for the Blue Coated aluminum roof rainwater sample, and 11.7 NTU for the ambient source. Turbidity recommendation by USEPA [24] is around one (1) NTU maximum for portable use of harvested water. Nitrate (NO3) is the most chemically stable form of nitrogen unlike nitrite (NO2) which is relatively unstable intermediate in the conversion between nitrate and ammonia [1]. Nitrate concentration in the samples show higher values of 0.05 mg/L for rainwater from Asbestos, thatch and blue coated aluminum roofs. This high value is also noted in ambient rainwater obtained in the thatch roof vicinity. These values are below the USEPA drinking water maximum contaminant limit (MCL) of 10 mg/L nitrate [24].

Total dissolved solid TDS concentrations were generally low compared with allowable limit of 500 mg/L for drinking water [27]. TDS ranges from 1.80 – 31.6 mg/L in rainwater from rooftops and 1.4 – 26.9 mg/L in ambient rainwater. High TDS content also signifies the presence of ions such as nitrate, aluminum, copper and lead that are above the standards for drinking water [1]. Water with a very low TDS concentration might be corrosive, causing toxic metals such as copper and lead to leach from the roofing materials which may pose a health risk [13]. Total suspended solids (TSS) in the harvested rainwater under the different rooftops show relative variability. TSS in rainwater from Cameroon zinc roof at Ikot Ebo were below detectable value while a general mean value of 4.8 mg/L was obtain for the various roofs rainwater samples and 3.4 mg/L for ambient source. Higher concentration of suspended solids can serve as carriers of toxics, which readily cling to suspended particles. This could make drinking such water unpalatable [1].

Fe, Cu and Ni are the main metals leaching from roofs in the region under study. Significant presence of metals is noted for rainwater obtained from asbestos, rusted roof and blue coated aluminum roofs ranging between 0.045 – 0.053 mg/L for Fe, 0.015 mg/L Cu for thatch roof and 0.008 – 0.028 mg/L for Ni. Similar results were obtained for the ambient rainwater samples. The main sources of Cu in urban runoff are roof corrosion. The WHO limit for concentrations of Cu is 0.01 [27]. Precipitation intensity also influences the concentration of micro – pollutant in rooftop runoffs as light rainfall results in higher concentrations than heavy rainfall [12]. This may be due to the longer contact time during light rainfall. In addition, the exposure direction also affects the concentration, with highest micro – pollutants concentration found from runoff of roofs facing prevailing wind [1].

6 Conclusion

We have examined the physicochemical characteristics and micro pollutants (heavy metals) content in rainwater from various roof runoffs in the region of study. We conclude that rainwater runoff from the region was not suitable for direct ingestion. The activities of the oil and gas exploration companies in the region could contribute to the contaminants noted in the results. We therefore recommend proper treatment of the rainwater from roof runoffs before ingestion. Rainwater obtained from asbestos roofing materials should be thoroughly treated before usage as they retain very high values of contaminants and micro-pollutants. Further research in other parts of the state is also recommended to properly map – out regions with higher rainwater contamination. This will also aid decision making and enable initiation of policies to check environmental pollution in the region.

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